Assessment of Environmental Impacts Resulting from Ground Vibrations due to Piling Activities and Railway Transport

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Abstract

With the development of the country's economy, industrial activities close to urbanized areas have inceased tremendously. These activities are sources of ground vibrations impacting on human life. Resulting annoyance conditions near residential areas and possible human response to ground vibrations have been investigated in this study. Ground vibration have been monitored at precast pile driving sites and at a location close to Panadura-Moratuwa railway line using an A4-channel seismograph. Human perception and disturbance conditions associated with each location is discussed with the criteria given in British Standards. According to the ground vibrations levels measured at the piling site, up to 55 m distance from pile driving locations perceptible level of ground vibrations have been occurred thus caving annoyance to occupants. Zone with adverse comments, extends up to 37 m from the pile and adverse comment possible zone extend up to 50 m from the pile when using pile diver and piles with given specifications. According to ground vibration levels near the railway track, occupants in residential areas will experience annoyance as residential area contains ground vibrations in perceptible amount. Up to 27 m distance from the railway track, ground vibrations levels were measured up to a level of making complaints regarding annoyance made by train.The trench already existed near the railway track (parallel to the rail way track) is capable of reducing ground vibration levels up to 40%.

Keywords: Disturbances, Piling Impact, People Annoyance, Human Response

1 Introduction

The population of the world's urbanized areas have increased by 200,000 people per day as an average during the period of 2010 to 2015 [1]. Therefore, the necessity for, infrastructure and transport facilities and due to the increasing population thus increasing industrial and construction activities in the residential areas. Ground vibrations associated with these activities interfere with human life.

Structural vibrations in buildings can be felt by the occupants and can affect them in many ways such as reduction of the quality of life and their working efficiency [2]. This is a least discussed topic in Sri Lanka as people may have got used to these adverse circumstances. However, investigation into vibration and evaluation of human exposure to those induced by construction activities and transport systems is very important in maintaining the required quality of life.

Piles are relatively long, slender members that transmit foundation loads through soil strata of low bearing capacity to deeper soil or rock strata having a high bearing capacity [3]. Two methods are commonly used for driving piles into soil,the impact or recursive hammer and the vibratory hammer. Pile driving by impact driving generates continues vibrations with lower frequencies ranging from about 10 to 50 Hz. Bored piling method induces lower magnitude ground vibration with higher frequencies. Ground vibrations induced from impact piling is more significant as they generate higher magnitude seismic waves with low frequency [4]. There are two types of impact hammers, hydraulic hammer and diesel hammer.Impact hammers produce intermittent vibrations [5].

Ground vibrations due to railway transport are in the frequency range from 40 to 80 Hz; the lower frequencies being especially associated with heavy freight trains. A fall of 10 dB typically occurs by 100 Hz and a further 50 dB by 250 Hz. Measurements indicate vibration levels in a similar range to road-generated vibration, that is, from 0.1 to 1.0 mm/s [6].

Type of the suspension, wheel condition, track surface conditions, track support system type, speed of the train, track structure, soil type, and rock layers are some governing factors of ground vibration due to railway transport [7].

Human perception and response to ground vibration varies widely. It depends on the individual's sensitivity, the frequency, peak particle velocity (PPV), duration, and on whether or not the event is expected and if so, whether the vibration is expected to cause damage. A person working in a factory is likely to be less sensitive to vibration than that same person would be quietly reading a book in a residential home. Most routine complaints of vibration come from people who are ill, elderly, or are engaged in a vibration sensitive hobby or activity [8].

The occupants will be affected in many ways. After or during exposure of time whole-body vibration can cause fatigue, stomach problems, headache, loss of balance and "shakiness" shortly. After daily exposure over several years, whole-body vibration can affect the entire body and result in many health disorders [9].

People can typically perceive vibrations above 0.254 mms^{-1} and vibrations above 2.54 mms^{-1} can be troublesome to people. People can feel and become concerned about vibrations that are only 1/100th of those that might begin to cause damage to structures [10].

Reducing ground borne vibrations due to industrial and transportation activities in urban areas is a very challenging task. Many mitigation measures can be considered, and different types of wave barriers can be applied such as, open or in filled trenches, rows of tubular or solid piles, very stiff concrete walls or very flexible gas cushions which diffract those surface waves were studied in detail. Among these trenches are considered very effective [5].

Venkatesh (2008) carried out a study on "Reduction of Blast Induced Ground Vibrations with Open Trenches in Surface Mines". Trench, 16 m deep, 20 m wide and 200 m long and situated at a distance of 300 m from the top bench resulted in an average reduction of 25% PPV without taking effect of attenuation of the vibrations due to distance between two geophones [11].

2 Methodology

2.1 Site Selection

Piling site using impact piling method, located in an urban area and a location near the Moratuwa-Panadura railway line were selected.

2.2 Data Acquisition

Vibrations measurement points are located in 10 m intervals and selected locations are marked using metal pegs. GPS location data are acquired using hand held GPS at each location. Figure 1 shows proposed data acquisition map.

Other information related to piling operations such as information about pile driver, piling depths, hammer weight, hammer drop height, interval between each drop and total time used in pile drivin gare collected from site supervisors and site engineers.

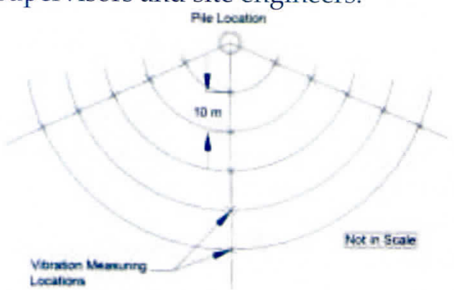

Figure 1 - Survey plan for measuring of ground vibrations on a piling site

A survey line is placed perpendicular to the railway track and six locations were selected to measure ground vibrations as shown in Figure 2. As a trench (road site sewage drain) exist by the side of railway line, effect of the trench in altering the ground vibrations was also measured by placing two vibration monitors straddling the two sides of the trench. Those locations were marked as location 01 and 02 in Figure 2.

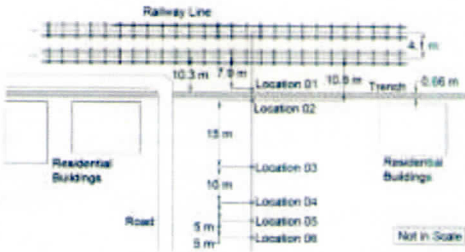

Figure 2 - Survey plan for measuring ground vibrations near railway line

All the locations are marked with metal pegs on the ground, and GPS location data are also acquired. As only three vibration monitors were available, only 3 readings would be taken at a time, when a train passes the site. Locations of vibration monitors are changed to different locations as marked in Figure 2 to cover the entire survey line. The time taken by each train to pass the location is also measured, while ground vibration data is acquired. The survey at the particular location have been conducted during day time. Then, total time taken by all the trains to pass the location is calculated.

2.3 Ground Vibration Level Analysis

Ground vibration data analysis has done in two methods. They are,

1. Comparing the PPV values recorded with the standard values stated in British Standards.
2. Calculating the Vibration Dose Values, and finding the probable human response on each site.

According to BS 5228-2:2009, highest peak particle velocity (PPV) values are divided into four ranges which are based in terms of human perception and disturbance.

Table 1 - Human disturbance and perception level change with ground vibration level ranges

Condi-tion	PPV Range (mms^{-1})	Degree of human perception and disturbance
01	0.14 – 0.3	Vibration might be just perceptible in the most sensitive situations for most vibration frequencies associated with construction. At lower frequencies, people are less sensitive tovibration.
02	0.3 – 1.0	Vibration might be just perceptible in residential environments
03	1.0 – 10	It is likely that vibration of this level in residential environments will cause complaint, but can be tolerated if prior warning and explanation has been given to residents.
04	> 10	Vibration is likely to be intolerable for any more than a very brief exposure to this level.

Vibration dose values can be used to assess the severity of impulsive and intermittent vibration. This is a time dependent parameter, thus human exposure to ground vibrations is measured with time in here [12]. It is estimated by Equation 1.

$$VDV = 51.6\, xPPV \text{ x } t^{0.25} \text{---------Eq. (1)}$$

Where,

- PPV = Peak Particle Velocity (ms^{-1}).
- T = Total duration of vibration exposure (s).

Calculated vibration dose values are evaluated according to BS6472. Probable human response associated with measured vibration levels are compared in each site according to following criteria as mentioned on BS 6472. They are,

- Low probability of adverse comment
- Adverse comment possible
- Adverse comment probable

Vibration Dose Value ranges with different human response levels are shown in Table 2.

Table 2 - Vibration dose values and their effects

Place	Low probability of adverse comment	Adverse comment possible	Adverse comment probable
Residential buildings (16 h day)	0.2 to 0.4	0.4 to 0.8	0.8 to 1.6
Residential buildings (8 h night)	0.13	0.26	0.51

Then, zones with above effects are demarcated using Surfer™ software.

3 Results and Discussion

3.1 Ground Vibration Levels at the Pile Driving Site

Specifications of the Piles and Pile Driver are,

- Type – Hydraulic Hammer
- Hammer Weight – 4 ton
- Hammer Drop Height – 1.2 m
- Cross section area of the pile – 400 cm^2

Categorization of each location accoding to human disturbance and perception conditions is shown in Table 3.

Table 3 - Human disturbance and perception condition at the pile driving site

Location No.	Distance from Pile (m)	PPV (mms^{-1})	Human disturbance and perception condition
1	8	3.39	3
2	20	2.66	3
3	30	1.92	3
4	40	1.10	3
5	50	0.57	2
6	60	0.17	1

Variation of PPV with the distance is graphically represented in Figure 3.

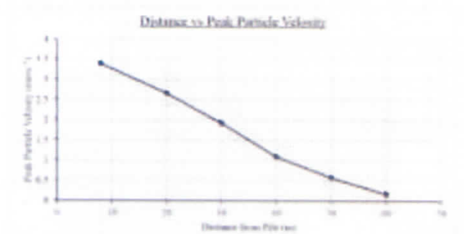

Figure 3 - Variation of PPV with distance in Piling Site

Zones with different human disturbance and perception conditions in response to the ground vibration levels recorded in piling site are graphically represented in Figure 4.

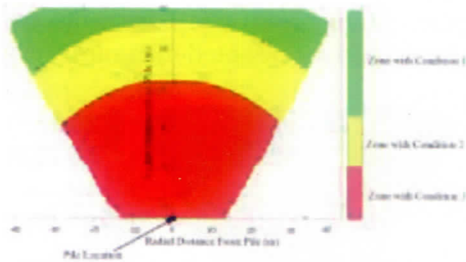

Figure 4 - Zones with different human disturbance and perception condition

Vibration Dose Value (VDV) Calculations.

- Total Time taken for driving one pile = 11 Minutes
- Amount of pile driven for a day = 2
- Total exposure time=2 x 11 x 60
- Total exposure time=1320 s

Evaluations of Vibration dose values are done according to Table 2.

Table 4 - Evaluation of Human Response in terms of Vibration Dose Value.

Location No.	Distance from the Pile (m)	Evaluation
1	8	Adverse comment probable
2	20	Adverse comment probable
3	30	Adverse comment possible
4	40	Low probability of adverse comment
5	50	-N/A-
6	60	-N/A-

Table 4 show the prediction of adverse comments by the occupants in the residential building near the pile driving site. Possibility of adverse comments varies with distance from the pile. Zones with different possibilities of adverse comments are graphically represented in Figure 5.

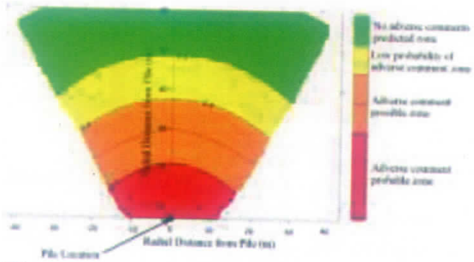

Figure 5 - Zones with different possibilities of adverse comments in pile driving site.

3.2 Ground Vibration Levels near the Panadura-Moratuwa Railway Line

During the site visit, ground vibration levels were measured in the course of passage of 13 trains. The time taken by each train to pass the site was recorded. All the readings were taken while changing the locations of geophones to different locations as marked in Figure 2. As there were two parallel railway tracks at the location, average distance from railway tracks to geophones is considered in all calculations.

Based on the ground vibration data acquired on the site, degree of human perception and disturbance associated with each location is categorized according to the criteria shown in Table 2.

Table 5 shows the categorization of each location near the railway track based on degree of human perception and disturbance.

Table 5 - Human disturbance and perception condition conditions near the railway track

Location No.	Distance from Railway track (m)	Average PPV (mms^{-1})	Associated Human disturbance and perception condition
02	10	5.71	3
03	12.8	3.45	3
04	27.4	1.03	3
05	37.4	0.65	2
06	42.4	0.61	2
07	47.4	0.48	2

Variation of PPV with the distance is graphically represented in Figure 6.

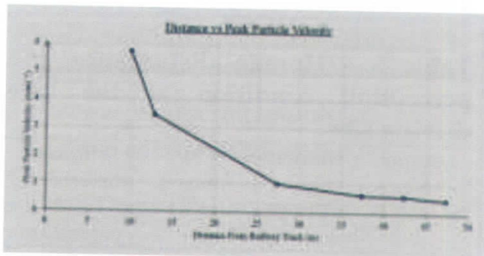

Figure 6 - Variation of PPV with distance near railway track.

Zones with different human disturbance and perception condition are graphically represented in Figure 7.

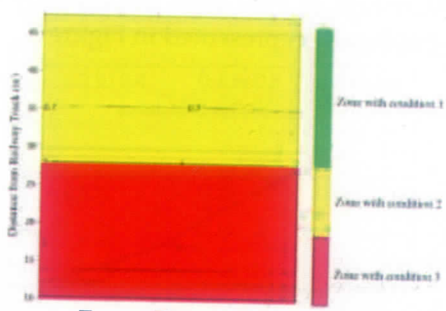

Figure 7 - Zones with different human disturbance and perception condition

Vibration dose values are calculated using Eq. (1). As the data related to all the trains during day time is not available, vibration dose values for each train is calculate at each location where ground vibration data is available. Then weighted average of VDV is calculated by multiplying the dose values at the location with the PPV value as PPV value has most prominent effect on VDV.

Total exposure time = Time taken by the train to pass the location

$$Weighted\ Average\ of\ Vibration\ Dose\ Value = \frac{\sum PPV \times VDV}{\sum PPV}$$

$$Weighted\ Average\ of\ Vibration\ Dose\ Value = \frac{0.05048}{0.07429}$$

$$Weighted\ Average\ of\ Vibration\ Dose\ Value = 0.679\ ms^{-1.75}$$

Using the same methodology, VDV values are calculated for all 6 locations. Those are shown in Table6.

Table 6 - Average VDV for a train at different locations

Location No.	Distance from Railway Track	Average Vibration Dose Value per Train ($ms^{-1.75}$)
01	10	0.679
02	12.8	0.375
03	27.4	0.101
04	37.4	0.0615
05	42.4	0.0581
06	47.4	0.0459

Zones with different possibilities of adverse comments are graphically represented in Figure 8.

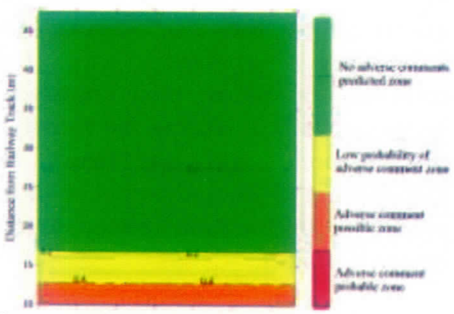

Figure 8 - Zones with different possibilities of adverse comments near railway track

3.3 Effect of the Trench to Reduce Ground Vibrations

The trench is situated near the railway track, running parallel to the track. Total of eight vibrations readings were taken at two sides of the trench. Dimensions of the trench is shown in Figure 9.

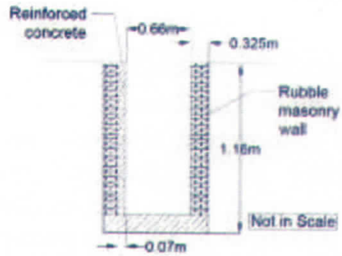

Figure 9 - Dimensions of the Trench

Reduction of ground vibration levels due to the trench was calculated as a percentage. The results are shown in Table 7.

Table 7 - Ground vibrations measurements near trench

No.	PPV before Trench (mms^{-1})	PPV after Trench (mms^{-1})	% Drop of PPV
01	5.01	2.94	41.3
02	5.33	3.10	41.7
03	13.64	5.92	56.6
04	2.63	1.83	30.5
05	5.30	3.63	31.5
06	8.11	4.61	43.1
07	7.72	3.82	50.4
08	2.70	1.79	33.8

$$Average\ Vibration\ drop\ percentage = \frac{329.2}{8}$$

$$Average\ Vibration\ drop\ percentage = 41.1\ \%$$

Reduction of PPV after the trench is graphically shown in figure 10.

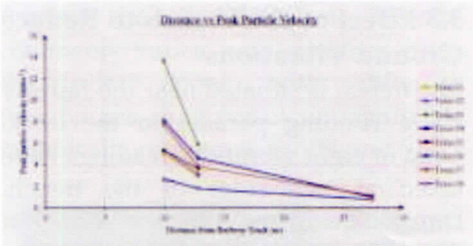

Figure 10 - Reduction of PPV from the trench

4. Conclusion and Recommendations

When considering the pile driving, according to the analyzed ground vibration data, up to a 55 m distance from pile driving locations perceptible amount of ground vibrations have occurred thus creating an annoyance to occupants. When the analysis is done in terms of vibration dose value, adverse comments probable zone extends up to 37 m from the pile and adverse comment possible zone extend up to 50 m from the pile. Therefore, residential buildings should be located at least 55 m away from the pile location when using pile diver and piles with given specifications. This will ensure least disturbances to general public.

Considering ground vibration levels near the railway line, occupants in residential areas will experience annoyance with ground vibration at perceptible levels. Up to 27 m from the railway track, ground vibration levels rise up to a level of making complaints. Therefore, suitable method should be applied to reduce ground vibration levels generated by rolling stock. Average vibration dose value per train suggest that, adverse comments possible zone is extending up to 12 m from the railway track and low probability of adverse comments upto 17 m from the railway track per train. However, in order to calculate the total vibration dose value in day time, the VDV value should be multiplied with total number of trains passing in the day time.

When the effect of trench is considered, it is capable of reducing ground vibrations up to 41.1%. However, the particular trench running parallel to the track is not capable of reducing ground vibrations up to a level of recommended level with least annoyance to the occupants. Therefore, more ground vibration reducing measures should be applied near the railway track to ensure least disturbance to the general public.

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